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BALLOONING SPIDERS IN MISSOURI, USA, AND NEW SOUTH WALES, AUSTRALIA: FAMILY AND MASS DISTRIBUTIONS

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ABSTRACT

Ballooning spiders were captured during a full growing season over agricultural habitats in Missouri, USA, and one week in New South Wales, Australia, using sticky traps in Missouri and tow nets in Australia. More than 2,000 spiders in Missouri and more than 800 spiders in Australia were identified to family and estimates made of their live masses. Both aeronaut faunas are dominated by the family Linyphiidae, with the remaining families making up different proportions at the two sites. The vast majority of aeronauts weighed between 0.2 and 1.0 mg, with the mass-frequency distributions at both sites tailing off rapidly beyond 2.0 mg. The most massive Missouri aeronaut weighed 25.5 mg, and the most massive Australian aeronaut 19.1 mg. These are the first published extensive data on the live masses of ballooning spiders from the field and this is the first taxonomic analysis of a Southern Hemisphere aeronaut fauna.

INTRODUCTION

There is a large and well established literature on aerial migration of terrestrial arthropods (see Johnson 1969 and Dingle 1978 and 1980 for reviews). Not surprisingly it is dominated by the insects, whose large size, instances of mass seasonal dispersal, and agricultural pest status call attention to them. However insects are not the only aerially dispersing terrestrial arthropods (Southwood 1962). The most conspicuous of the remaining groups are the spiders (Arachnida: Araneae). Like the insects, spiders disperse aerially in enormous numbers (Comstock 1948), often seasonally (Emerton 1908; Bristowe 1929; Duffey 1956), and may in this way travel hundreds of kilometers (Holzapfel and Perkins 1969; Okumo and Kisimoto 1981). Unlike the insects, they lack wings, being instead lifted and carried passively on silken threads in the process known as ballooning. Spiders have considerable potential as agents of biological control of pests (Riechert and Lockley 1984), so their capacity to disperse is of more than theoretical interest, especially in annual crop systems which they must recolonize at the beginning of each growing season along with the insect pests on which they feed.

Insects lighter than aphids and as massive as plague locusts are known to disperse aerially. There has only been one restricted data set available on the masses of ballooning spiders (Coyle et al. 1985). We have been able to gather large samples of such data as a part of long-term studies on terrestrial arthropod dispersal in Missouri, USA and New South Wales, Australia. Since all previous taxonomic data on aeronauts are exclusively from the Northern Hemisphere, we also feel it is valuable to present the family distributions of aeronauts from both sites.

METHODS

The Missouri site was a 2.0 ha field at the University of Missouri South Farms, 9.7 km SE of the city of Columbia in Boone Co., planted to soybeans with varying admixtures of sunflowers as part of a study on the influence of cropping scheme on natural enemy diversity (N. L. Marston, pers. comm.). Panel sticky traps made of 12.7 mm (1/2 in) and 6.35 mm (1/4 in) galvanized hardware cloth coated with the adhesive Tack Trap® (Animal Repellents, Inc., Griffin, GA.) were run for eighteen consecutive one-week periods beginning on June 15, 1983. The traps were mounted on an open frame and covered a total area of 3.0 m^2 between 0.5 and 2.0 m elevation. All vegetation was cleared from within 3.0 m of all traps by application of the herbicide Roundup® (Monsanto Co., St. Louis, MO) to maximize the probability that all trapped spiders had been ballooning rather than travelling on bridge lines. For the same reason the trap supports were coated with adhesive to ensure that walking spiders would be intercepted rather than spuriously trapped (see Greenstone et al. 1985a, for complete description of trapping system). The traps were returned to the laboratory for examination at 6X with a stereo microscope, and the spiders placed in paint thinner to remove the adhesive. After four days the spiders were transferred to toluene and after a further four days to 70% ethanol for final preservation. The traps were cleaned with solvent, recoated in the laboratory and replaced in the field each week.

The Australian site was at Trangie in the Central Western Plains of New South Wales, in native pastures derived from cleared savannah woodland adjacent to fields of wheat and dryland lucerne. Spiders were sampled by tow net from both the surface boundary layer, at 3.0 m, and the planetary boundary layer, between 100 and 300 m elevation. The net, which had a 1.0 m^2 opening, was supported by a mast at the lower elevation and by a kite in the upper air. The kite was deployed in a way which minimized arthropod catches during ascent and descent (Farrow and Dowse 1984). The samples of arthropods were immediately preserved in 70% ethanol and the spiders were subsequently separated in the laboratory. Unlike the Missouri sampler the net is dependent upon favorable winds for its deployment, so that sampling at the Australian site was not continuous and the individual sampling periods were relatively short (1-6 h). We present only data from November 23-30, 1979, which had the largest proportion of spiders of the samples taken in the Trangie sampling program.

After the spiders had been preserved in ethanol for at least three months, the masses of all of the Australian spiders and a representative sample of the

Missouri spiders were estimated by means of a volumetric mass estimate derived from a series of linear measurements (Greenstone et al. 1985b); this estimate is not affected by the differences in methods of trapping and preservation at the two sites and stabilizes after six weeks of ethanol preservation (Greenstone et al. 1985c). We also identified the spiders to family. Although a few species can be confidently identified to genus and even species (e.g. the *Oxyopes* and *Tetragnatha* species, which were represented by one or a few species at each site), the vast majority of aeronauts are minute immatures so that genus or species level identification would require a major basic research effort in systematics (J. Coddington pers. comm.).

RESULTS AND DISCUSSION

Family-frequency distributions for the Missouri and Trangie samples are shown in Figs. 1A and 1B, respectively. The family Linyphiidae dominates in both cases, with 42% and 52% of the individuals, respectively (we follow Millidge 1980 in including the Erigonidae and Micryphantidae of some authors in this family). The Araneidae and Oxyopidae each make up between 9% and 17% of the total, with the remaining families differing in dominance between the two sites. The same proportion of unidentifiable animals, about seven percent, was found at both sites, reflecting comparable incidences of damage to spiders whether collected by sticky trap or tow net.

The mass-frequency distributions are shown in Figs. 2A and 2B. More than half of the aeronauts at both sites are in the first two mass classes (0.21 and 0.60 mg) and the vast majority, 85% in Missouri and 94% in Trangie, weigh 1.0 mg or less. The most massive spiders collected weighed 25.5 mg and 19.1 mg, respectively.

About 14% of identified Missouri aeronauts and 32% of identified Trangie aeronauts were adults (Table 1). However the percentages for linyphiids alone are 31 and 58, respectively. In both cases the sex ratio is not significantly different from 1.0 ($p > 0.15$ and $p > 0.99$, Binomial Test, Siegel 1956). The large proportion of adults among linyphiid aeronauts has been noted by other workers but females have predominated in these earlier studies (Duffey 1956; Meijer 1977; Salmon and Horner 1977).

The Trangie collection is the first from the Southern Hemisphere to be analyzed taxonomically. Because it covers only one week's data, no detailed comparisons with Northern Hemisphere collections are made here. However the same families appear to be involved in the aeronaut fauna of the most isolated of Southern Hemisphere continents as in the better-studied Holarctic, so that the ecology and evolution of ballooning behavior are probably little influenced by Australian endemicity.

The linyphiids dominate most of the ballooning literature, which has emphasized mid to high latitude Northern Hemisphere sites, where the linyphiids predominate on the ground as well as in the air (Bristowe 1929; Enders 1975). Their domination of the Missouri (N. Latitude 38° 58') samples was therefore to be expected. The linyphiids are of particular interest because a high proportion balloon as adults, when they have high reproductive value and hence high colonizing potential (MacArthur and Wilson 1967; Greenstone 1982). Further-

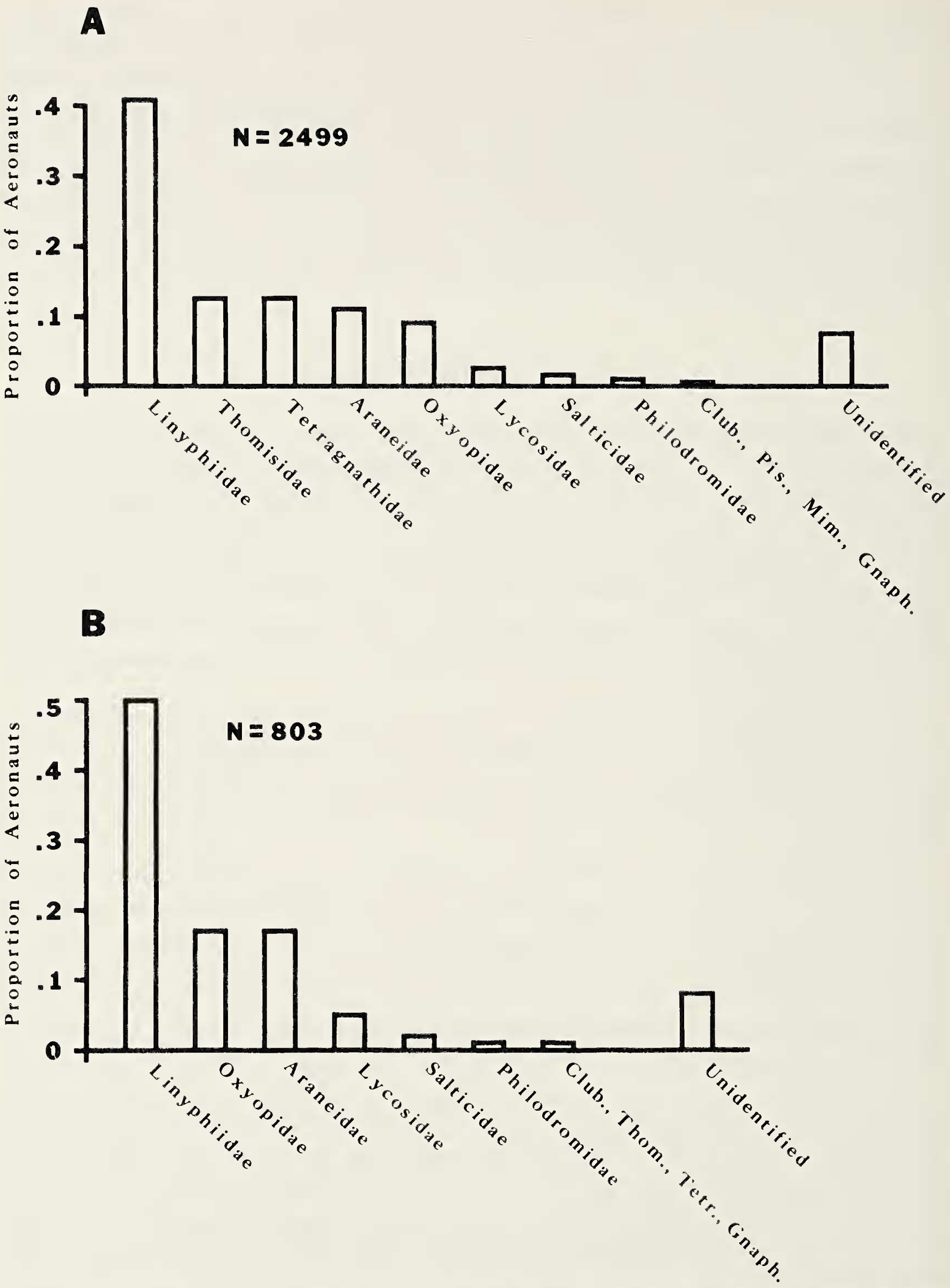

Fig. 1.—Family-frequency distributions for aeronauts captured in Missouri (A) and Trangie (B). Abbreviations: Club. = Clubionidae; Gnaph. = Gnaphosidae; Mim. = Mimetidae; Pis. = Pisauridae; Tetr. = Tetragnathidae; Thom. = Thomisidae.

more they are known to be important predators in at least some agricultural systems (Riechert and Lockley 1984).

Fig. 2A depicts a very large data set collected throughout an entire growing season and is therefore a definitive estimate of the mass frequency distribution of

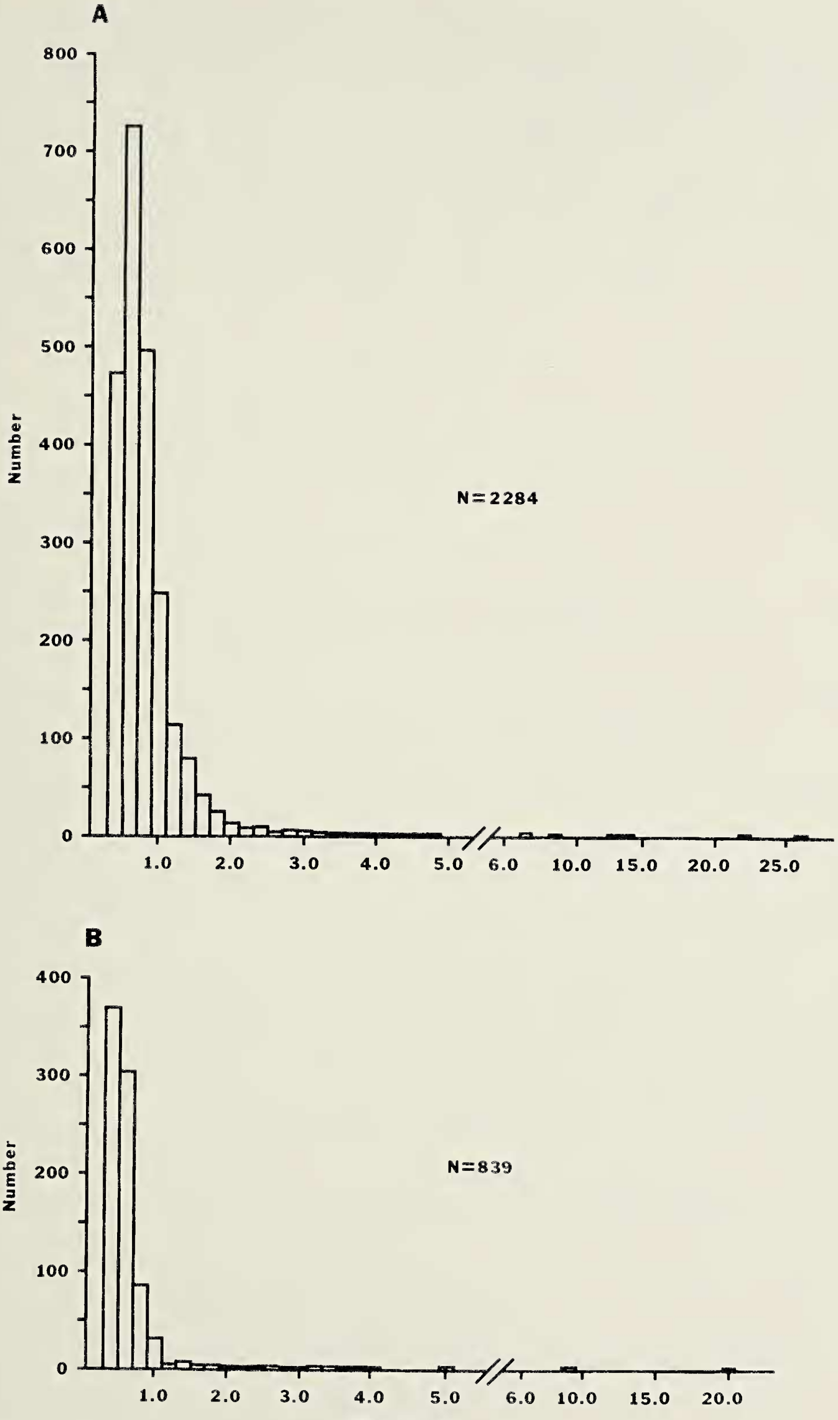

Fig. 2.—Mass-frequency distributions for aeronauts captured in Missouri (A) and Trangie (B). Mass classes are 0.2 mg wide below 6.0 mg and 1.0 mg wide beyond 6.0 mg. Class marks denote upper bound of each mass class.

Table 1.—Age, sex, and taxonomic representation of identified aeronauts. M = male, F = female, I = immature, % = percent of fauna represented by family. Percentages in this table differ from those in Fig. 1 due to exclusion of unidentified animals. *Gnaphosids and mimetids represent less than 0.1% of the identified Missouri animals.

	MISSOURI				TRANGIE			
Family	M	F	I	%	M	F	I	%
Linyphiidae	160	161	716	44.9	105	127	171	54.2
Araneidae	4	0	266	11.7	6	1	131	18.6
Oxyopidae	0	0	231	10.0	0	1	138	18.7
Thomisidae	1	0	314	13.6	0	0	3	0.4
Tetragnathidae	0	0	312	13.5	0	0	1	0.1
Lycosidae	0	0	68	2.9	0	0	37	5.0
Salticidae	1	0	36	1.6	0	0	13	1.8
Philodromidae	0	0	28	1.2	0	0	6	0.8
Clubionidae	1	0	7	0.4	0	0	3	0.4
Gnaphosidae	0	0	1	*	0	1	0	0.1
Pisauridae	0	0	2	0.1	—	—	—	—
Mimetidae	0	0	1	*	—	—	—	—

aeronauts. Clearly most ballooners weigh 1.0 mg or less, and ballooners heavier than 30 mg are unlikely. (Note that there are no aeronauts weighing less than 0.21 mg).

There are three possible contributors to the mass-frequency distributions of aeronauts, viz., the mass-frequency distributions of *potential* aeronauts, the ballooning tendencies of spiders of different mass classes, and the effect of atmospheric lift on the dynamics of ballooning. The mass-frequency distributions of spiders collected from the ground and vegetation do favor smaller animals, but they are not as markedly skewed as those in Fig. 2 (Waldorf 1976; Nentwig 1982), and spiders weighing more than 26 mg are common. Certainly there is no inherent physical barrier to ballooning by more massive animals, which could simply produce more ballooning silk (R. Buskirk and R. B. Suter, pers. comm.). Therefore, the lack of larger ballooners is probably due, at least in part, to reductions in ballooning tendency with increasing mass. Such reductions have been documented by behavioral assays of ballooning in the lycosid genus *Pardosa* (Richter 1970). Variables selecting against ballooning by more massive animals might include enhanced visibility to aerial predators, decreased lift, and increased risk of injury on landing (Coyle et al. 1985).

With few notable exceptions (Glick 1939; Glick and Noble 1961; Holzapfel and Perkins 1969; Okuma and Kisimoto 1981), all aeronaut collections, including those made in this study in Missouri, have been made from elevations less than 3.0 m, where ballooning spiders may be simply drifting back towards the ground following launching from a high take-off point. The ascent of spiders into the upper air depends on convective updrafts and is affected not only by the velocity of the updraft but also by the mass of the spider and by the drag of the silk thread and balloon. Unless updrafts are strong there will be a tendency for the lighter mass classes to be better represented in the upper air compared with the surface due to differential settling rates. We will use a larger Trangie data set to compare upper and lower elevation mass-frequency distributions in a future publication (in preparation).

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LITERATURE CITED

Bristowe, W. S. 1929. The distribution and dispersal of spiders. Proc. Zool. Soc. London, 43:633-65.

Comstock, J. H. 1948. The Spider Book. Cornell University Press, Ithaca.

Coyle, F. A., M. H. Greenstone, A.-L. Hultsch and C. E. Morgan. 1985. Ballooning mygalomorphs: estimates of the masses of *Sphodros* and *Ummidia* ballooners (Araneae: Atypidae; Ctenizidae). J. Arachnol., 13:291-296.

Dingle, H. 1978. (ed.) Evolution of Insect Migration and Diapause. Springer-Verlag, New York.

Dingle, H. 1980. Ecology and evolution of migration. *In* Animal Migration, Orientation, and Navagation. (S. A. Gautreaux, Jr., ed.). Academic Press, New York, pp. 1-101.

Duffey, E. 1956. Aerial dispersal in a known spider population. J. Anim. Ecol., 25:85-111.

Emerton, J. H. 1908. Autumn flights of spiders. Psyche, 15:121.

Enders, F. 1975. The influence of hunting manner on prey size, particularly in spiders with long attack distances (Araneidae, Linyphiidae and Salticidae). American Natur., 109:737-762.

Farrow, R. A. and J. E. Dowse. 1984. Method of using kites to carry tow nets in the upper air for sampling migrating insects and its application to radar entomology. Bull. Entomol. Res., 74:87-95.

Glick, P. A. 1939. The distribution of insects, spiders, and mites in the air. U.S. Dept. Agric. Bull., 673:1-150.

Glick, P. A. and L. W. Noble. 1961. Airborne movement of the pink bollworm and other arthropods. U.S. Dept. Agric. Tech. Bull., 1255:1-20.

Greenstone, M. H. 1982. Ballooning frequency and habitat predictability in two wolf spider species (Lycosidae: *Pardosa*). Florida Entomol., 65:83-89.

Greenstone, M. H., C. E. Morgan and A.-L. Hultsch. 1985a. Spider ballooning: development and evaluation of field trapping methods (Arachnida: Araneae). J. Arachnol., 13:337-345.

Greenstone, M. H., C. E. Morgan and A.-L. Hultsch. 1985b. Ballooning methodology: equations for estimating the masses of sticky-trapped spiders. J. Arachnol., 13:225-230.

Greenstone, M. H., A.-L. Hultsch and C. E. Morgan. 1985c. Effects of preservative and preservation time on volumetric mass estimates of spiders (Araneae). J. Arachnol., 13:406-408.

Holzapfel, E. P. and B. D. Perkins, Jr. 1969. Trapping of air-borne insects on ships in the Pacific, part 7. Pacific Insects, 11:455-476.

Johnson, G. 1969. Migration and Dispersal of Insects by Flight. Methuen, London.

MacArthur, R. H. and E. O. Wilson. 1967. The Theory of Island Biogeography. Princeton Univ. Press, Princeton.

Meijer, J. 1977. The immigration of spiders (Araneida) into a new polder. Ecol. Entomol., 2:81-90.

Millidge, A. F. 1980. The erigonine spiders of North America. Part 1. Introduction and taxonomic background (Araneae: Linyphiidae). J. Arachnol., 8:97-107.

Nentwig, W. 1982. Epigeic spiders, their potential prey and competitors: relationship between size and frequency. Oecologia, 55:130-136.

Okuma, C. and R. Kisimoto. 1981. Air borne spiders collected over the East China Sea. Japanese J. Appl. Entomol. Zool., 25:296-298.

Richter, C. J. J. 1970. Aerial dispersal in relation to habitat in eight wolf spider species (*Pardosa*: Araneae: Lycosidae). Oecologia, 5:200-214.

Riechert, S. E. and T. Lockley. 1984. Spiders as biological control agents. Ann. Rev. Entomol., 29:299-320.

Salmon, T. and N. V. Horner. 1977. Aerial dispersion of spiders in North Central Texas. J. Arachnol., 5:153-157.

Siegel, S. 1956. Nonparametric Statistics. McGraw Hill, New York.

Southwood, T. R. E. 1962. Migration of terrestrial arthropods in relation to habitat. Biol. Rev. Cambridge Phil. Soc., 37:171-214.

Waldorf, E. S. 1976. Spider size, microhabitat selection, and use of food. Amer. Midl. Nat., 96:76-87.

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